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Optimization of a thermal-CVD system for carbon nanotube growth

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Abstract

We illustrate the optimization of the operation of a thermal chemical vapor deposition (CVD) system for the growth of carbon nanotubes (CNT). We have studied the deposition parameters using the Taguchi matrix robust design approach. The CVD system, which employs solid precursors (camphor and ferrocene) carried by nitrogen gas flow through a hot deposition zone, where the deposition of carbon nanostructures takes place, involves a large number of tunable parameters that have to be optimized.

With the aim of getting the best configuration for the development of massive and well-oriented CNT carpets, the Taguchi method allowed us to improve our system leading to the growth of extremely long CNTs (few millimeters) at a high deposition rate (500 nm/s) and yield (30% in weight of the carbon precursors feedstock), which were characterized by electron microscopy.

We found that the growth temperature had the most important influence on the CNT diameter, whereas the substrate tilt wit respect to gas flow did not influence their growth (i.e. CNTs grow on every side of the silicon wafer substrates, always normal to the substrate surface). The carrier gas flow and catalyst concentration both showed a secondary impact on CNT growth, though they showed a consistent correlation to the growth temperature.

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Keywords: Carbon nanotubes; High deposition rate; Taguchi robust design

1. Introduction

Carbon nanotubes (CNT) have received a great deal of attention in many research fields because of their unique physical and chemical properties. Since they were first reported [1], big efforts have been spent by the international scientific community in order to study their application in fields such as chemical and biological catalysis or separation, energy storage, composites for coating or filling [2,3], devices for molecular imaging or sensing [4], nanoelectronic devices, field emission devices [5] and so on.

One of the bottlenecks in the carbon nanotechnology is the growth process, which must be optimized for the achievement of worthwhile quantities of high-purity material. Compared to other growth techniques of CNT, such as arc discharge and laser ablation, chemical vapor deposition (CVD) is more suitable to satisfy the requirement of a high growth rate, without worsening the purity of the grown material.

The purpose of this work is to use the Taguchi methodology for the optimization of a previously reported [6] thermal-CVD system for the massive growth of vertically aligned multi-walled CNT. CVD is a growth technique which involves a large number of tunable parameters, such as the selection and concentration of the carbon precursor and catalyst, the choice of substrates, the type of carrier gas and its flow rate, the deposition temperature and the tilt of the substrate with respect to gas flow and other different technological and physical variables that have a dramatic influence on the nature and characteristics of the final material.

The Taguchi methods were developed by Genichi Taguchi between 1950 and 1960 to improve the implementation of total quality control in Japan [7]. They are based on a systematic methodology to design products whose performances are least affected by variations, i.e. noise, in the system.

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